How Galaxies Disguise Their Ages

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ABSTRACT

We calculate the contribution to Balmer line indices from far ultraviolet component sources. We find that this is significant, and may lead to identification of spurious age differences of the order of a total span of ~ 6 Gyrs or $\sim 15\%$ size bursts observed a few Gyrs after star formation stops. We suggest that claims for intermediate age populations in early-type galaxies may need to be reconsidered in the light of this new evidence.

Subject headings: galaxies: evolution — galaxies: stellar content

1. Introduction

For galaxies outside the Local Group, information on their stellar populations can only be obtained from integrated properties, such as colours and spectra. Unfortunately, integrated spectra and colours of composite stellar populations are known to be degenerate with respect to age and metallicity (e.g., Worthey 1994, for a recent discussion). For instance, the existence of a tight color-magnitude correlation for galaxies in nearby (Bower, Lucey & Ellis 1992) and distant (Stanford, Eisenhardt & Dickinson 1998) clusters is taken to imply that cluster galaxies form at high redshift over short timescales, whereas Schweizer & Seitzer (1992) are able to derive a tight $U - V$ vs. V correlation for field E/S0 galaxies, despite morphological and spectroscopic evidence for the existence of young stellar populations in these objects.

Worthey et al. (1994) have developed a system of narrowband spectrophotometric indices useful for separating age and metallicity effects in integrated spectra. Line strengths of Balmer line indices (Hβ, Hγ and Hδ) have been used to infer the presence of intermediate age populations in some early-type galaxies (e.g., Worthey 1997 and references therein). Jørgensen (1999) uses Hβ indices to infer the existence of a correlation between mean age and metal abundance for galaxies in the Coma cluster: young galaxies may masquerade among older objects because of their higher metal abundance, allowing a wide range of ages to be consistent with the passive evolution of the observed colour-magnitude relation and the small intrinsic scatter (Ferreras, Charlot & Silk 1999).

On the other hand, the population synthesis models used to derive theoretical index grids do not paint a complete picture of the stellar populations of early-type galaxies. The spectral energy distributions of these objects exhibit an unexpected rise in flux shortward of 2500 Å, a phenomenon dubbed the far ultraviolet (FUV) upturn (see O'Connell 1999 for a review). The currently accepted explanation for the FUV upturn is that it is caused by evolution of metal-rich stars on to the extreme Horizontal Branch (HB) and their UV-bright progeny (Brown et al. 1997 and references therein), whereas standard models terminate their evolution on the red clump on the HB (e.g., Sweigart 1987). FUV sources are known to exist in the metal rich, old "open" cluster NGC6791 (Liebert, Saffer & Green 1994) and are identified with field subdwarfs O and B in our own Galaxy (Saffer et al. 1997). These objects show strong, broad Balmer lines and may contribute significantly to Hβ, Hγ and Hδ indices. This is indeed the case for some metal poor globular clusters with long blue tails (de Freitas Pacheco & Barbuy 1995).

Nevertheless, these stars are not included in the population synthesis models of Worthey (1994), where HBs are treated as red clumps with a temperature offset. The isochrones of Bertelli et al. (1994) used by Vazdekis (1999) include an 'AGB-manque' phase for high metallicities, but only for low mass stars ($M < 0.60 M_{\odot}$) at large ages ($>$ 20 Gyr), whereas the existence of hot blue stars in NGC6791 and the field sdO/B show that stars of $\sim 1 M_{\odot}$, are able to evolve on to the extreme HB at ages of $\sim$ 10 Gyrs (Carraro, Girardi & Chiosi 1999). The models of Bressan, Chiosi & Tantalo (1996) predict FUV colours for galaxies of the appropriate ages and metallicities, but do not calculate Balmer line indices contributed from FUV sources, since fitting functions for stars of such high temperature and gravity are not yet available. Worthey, Dorman & Jones (1996) have computed the contribution to the integrated flux between 2000 and 2400 Å from a warm turnoff, and find that this may account for $\sim$ 50% of the observed luminosity, but do not explore the effect of HB sources on spectrophotometric indices.

The purpose of this *Letter* is to consider, to a first approximation, how FUV sources affect integrated Balmer line indices and therefore whether the claims for younger mean ages in some early-type galaxies may not be better explained by variations in HB morphology. We find that these objects provide a significant amount of Balmer line absorption and may therefore affect the derivation of ages via the Hβ, Hγ and Hδ indices.

2. Modelling

We adopt a semi-empirical approach in which we first estimate the fraction of extreme HB stars (and progeny) needed to produce the observed FUV colours, for two representative models at very different metallicities, and then compute the contribution from these objects to the total Balmer line absorption strength.

We use models by Dorman, O'Connell & Rood (1993a) in which a 10–30% fraction of HB stars evolves on to UV-bright phases. We use the two models for which detailed evolutionary calculations are presented by Dorman, Rood & O'Connell (1993b): one with [Fe/H]=+0.38, Y=0.292, $M_c = 0.464 M_\odot$ (where M_c is the core mass) and envelope masses of 0.003, 0.046 and 0.096 $M_\odot$ and a model with [Fe/H]=–1.48, Y=0.247, $M_c = 0.485 M_\odot$ and envelope masses of 0.003, 0.035 and 0.105 $M_\odot$. For each of these models we follow the prescriptions of Dorman et al. (1993a) to calculate FUV colours and their contribution to the total V band light.

We then use the evolutionary tracks presented in Dorman et al. (1993b) to estimate the fraction of total light at each T_{eff} and $\log g$ step and the stellar atmospheres of Kurucz (1993) to estimate the equivalent widths of Hβ, Hγ and Hδ at each stage. Since most of the models reach temperatures and gravities in excess of the grid calculated by Kurucz, we extrapolate Hβ,γ, δ equivalent widths to the appropriate $\mathrm{T}_{eff} - \log g$ range by means of polynomial fits to the predictions for the existing grid, being unable to completely simulate the spectrum of these objects. These are then summed, scaling by the fraction of total light produced, to yield the equivalent widths of Balmer lines contributed from FUV sources during their lifetime and again scaled by the fraction of total V band light to calculate the additional absorption line strength to integrated Hβ, Hγ and Hδ indices, following the prescriptions of Freitas Pacheco & Barbuy (1995). Table 1 shows the models used. Here column 1 is the fraction of blue HB stars, column 2 the contribution to the V band light, column 3 the 1550$-V$ color, column 4 the 2500$-V$ color and column 5 the extra Hβ strength provided by these stars. A header at the top indicates the model parameters and mean temperature of the models.

3. Discussion

Figure 1 shows the excess equivalent width of Hβ produced by HB stars and their progeny as a function of FUV colour of the host galaxy. We only plot the extra contribution to Balmer line strengths provided by these stars, without assuming any underlying model. We assume that the Balmer line strength produced by FUV sources can be added linearly to the chosen galaxy model from the Worthey (1994) compilation.

The range of FUV colours in the Burstein et al. (1988) sample is 2 to 4. From Figure 1, this corresponds to Hβ equivalent widths of up to 0.6 Å, with a typical contribution of 0.3 Å, in agreement with earlier results on metal poor globular clusters (de Freitas Pacheco & Barbuy 1995) and 'blue HB' simulations of Buzzoni, Mantegazza & Gariboldi (1994), albeit at lower temperatures than those of FUV sources. In our simulations, metal-poor HB stars yield somewhat higher Hβ strengths than those of metal-rich stars.

Figure 2 plots a single stellar population (SSP) model grid from Worthey (1994), and superposes the range of Hβ strengths contributed by FUV sources to an underlying 12 Gyr old population. We add index strengths for the SSP and the HB stars linearly, as stated above. We also show some of the higher signal-to-noise measurements of Trager et al. (1998). It can be seen that spurious age differences of $\sim 5-7$ Gyrs can be introduced by FUV sources; conversely, assuming that more complex stellar populations can be represented by linear combinations of SSP models, a 10–20% burst of star formation observed $1-3$ Gyrs after star formation ceases may be explained by FUV sources. Larger bursts observed at later ages can also be accounted for in this manner.

Figure 1 shows that a range of Hβ strengths is possible at any FUV colour. In turn, the spread in FUV colours at any age larger than 5 Gyr is significant (Tantalo et al. 1996). Taken at face value, this suggests some degeneracy in FUV colour, Hβ strength and age for early-type galaxies.

Our simulations show that the contribution to Hγ and Hδ are similar to Hβ. The model grid of Jones & Worthey (1995) spans about 0.2 Å, for a range of ages from 3 to 17 Gyrs. This suggests that FUV sources strongly affect these indices as well. On the other hand, the narrow H$\gamma_{A,F}$ and H$\delta_{A,F}$ indices of Worthey & Ottaviani (1997) appear to be much less sensitive to FUV source contributions, although in this case the narrowness of the index bandpasses probably requires more accurate modelling. The new Hγ index of Vazdekis & Arimoto (1999) varies by about 0.5 Å over ages of 1.6 to 17 Gyrs (depending on velocity dispersion). After correction for velocity dispersion, FUV source contribution can vary between 0 and 0.4 Å, spanning a sizeable portion of these newer grids.

Since Dorman et al. (1993b) do not present integrated fluxes for bands other then V, we are unable to estimate the effect of FUV sources on broadband colours. Nevertheless, the contribution to V from high metallicity models is typically 5% and always less than 10%, which should not affect broadband colors. For low metallicity models HB stars may provide as much as 20% of the light and this may produce bluer than expected colours. For comparison, the two globular clusters with long blue tails, M13 and NGC6229, are seen to have too blue integrated $U-B$ for their $B-V$ colour (Reed, Hesser & Shawl 1988).

An useful consistency check is to compare $2500-V$ colours for our models and observations. For high metallicity systems, Table 1 shows that we reproduce well the observed range of colours in the sample of Burstein et al. (1988), which is typically 3–4. Low metallicity models are far bluer, which is not surprising, since early-type galaxies are generally metal rich, but they are consistent with $2500 - V$ colours of globular clusters, which are typically 1.5–3.5 and span the appropriate metallicity range.

Figure 3 plots excess Hβ emission (over an 18 Gyr old population) for galaxies with index measurements from Trager et al. (1998) and FUV colours from Burstein et al. (1988). This was calculated following Davies, Sadler & Peletier (1993) and includes some galaxies for which they provide excess Hβ values. We find no significant correlation between ΔHβ and $1550{-}V$ colour, although some galaxies have both strong excess absorption and blue FUV colors. One of these galaxies, however, is NGC5102, the well known E+A galaxy.

This may imply that the effect of FUV sources on derived index strengths is weak. As shown in Table 1, the largest contribution to Hβ comes from objects with high surface temperature. Brown et al. (1997) estimate that the largest contribution to the FUV flux comes from stars with surface temperatures lower than 25,000 K. These sources would not provide large Hβ absorption, in agreement with the data presented in Figure 3. One caveat, is that FUV colors are measured through the large IUE aperture, which is generally wider than the slit sizes used to measure spectral indices: Ohl et al. (1998) show that FUV color gradients can be strong, making a comparison such as shown in Figure 3 possibly unrealistic.

We have chosen two of the Dorman et al. (1993b) tracks considered to best represent the FUV sources: it should be noted, however, that different objects, or different evolutionary tracks, may contribute to the FUV upturn: for instance post AGB stars are believed to be important in M31 (Bertola et al. 1995). The range of models used needs to be considerably expanded to include a wider range of objects to make these results more comprehensive.

There are a number of observational tests of our models: it is possible to measure indices for the 'quiescent' samples of Burstein et al. (1988) and Longo et al. (1989) in consistent apertures. Conversely, FUV strengths can be derived, from HST data, for Coma galaxies observed by Jørgensen (1999). It is also possible to explore the correlation of line strength indices with the distribution of FUV components observed by UIT (Brown et al. 1997). More accurate stellar atmospheres and fitting functions for hot, high gravity, metal rich stars are also necessary, to allow the FUV component effects to be accounted for in population synthesis models.

4. Conclusions

We have considered the FUV source contribution to Balmer line indices using a semi-empirical modelling technique. We find that this is significant and may lead to identification of spurious intermediate age populations or age gradients in galaxies. Nearly all Balmer line indices in use are potentially affected by FUV stars and consideration should be paid to their age sensitivity.

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FIGURE CAPTIONS

Figure 1: FUV colours vs Hβ strength produced by our models. The shaded region represents the range of FUV colours allowed by our simulations. A range of Balmer line strengths is possible at each colour.

Figure 2: A single stellar population grid of Hβ vs. [Fe/H] for different ages and abundances. We superpose the range of possible contributions from FUV sources to a 12 Gyr old population (dark bars). We also plot indices for high goodness galaxies (open circles) from the sample of Trager et al. (1998). Age differences of a few Gyrs, for old populations, or bursts of 10–20% size observed 1–3 Gyrs after star formation ceases, can be accounted for by FUV sources.

Figure 3: Excess Hβ emission vs. FUV colour, from the sample of galaxies in common to Trager et al. (1998), Davies et al. (1993) and Burstein et al. (1988). Excess Hβ is defined as in Davies et al. (see text).

Table 1. The Models

[Fe/H]	Y	M_c	M_{env}	$< T_{eff} >$	(f_b)	V contr.	1550$-V$	2500$-V$	Hβ (Å)
0.38	0.29	0.464	0.003	51000	0.1	0.02	2.57	4.10	0.07
0.38	0.29	0.464	0.003	51000	0.2	0.04	2.02	3.75	0.14
0.38	0.29	0.464	0.003	51000	0.3	0.05	1.64	3.48	0.21
0.38	0.29	0.464	0.046	28000	0.1	0.03	3.15	3.99	0.13
0.38	0.29	0.464	0.046	28000	0.2	0.06	2.80	3.61	0.26
0.38	0.29	0.464	0.046	28000	0.3	0.10	2.54	3.32	0.39
0.38	0.29	0.464	0.096	3000	0.1	0.02	3.62	4.66	0.01
0.38	0.29	0.464	0.096	3000	0.2	0.05	2.88	4.75	0.02
0.38	0.29	0.464	0.096	3000	0.3	0.07	2.43	4.84	0.03
–1.48	0.25	0.485	0.003	56500	0.1	0.06	2.98	2.07	0.17
–1.48	0.25	0.485	0.003	56500	0.2	0.12	2.32	2.01	0.34
–1.48	0.25	0.485	0.003	56500	0.3	0.18	1.93	1.94	0.51
–1.48	0.25	0.485	0.035	23000	0.1	0.06	2.91	2.05	0.18
–1.48	0.25	0.485	0.035	23000	0.2	0.12	2.37	1.96	0.36
–1.48	0.25	0.485	0.035	23000	0.3	0.17	2.00	1.87	0.54
–1.48	0.25	0.485	0.105	4000	0.1	0.02	3.35	2.01	0.02
–1.48	0.25	0.485	0.105	4000	0.2	0.05	2.95	1.91	0.04
–1.48	0.25	0.485	0.105	4000	0.3	0.07	2.65	1.80	0.06

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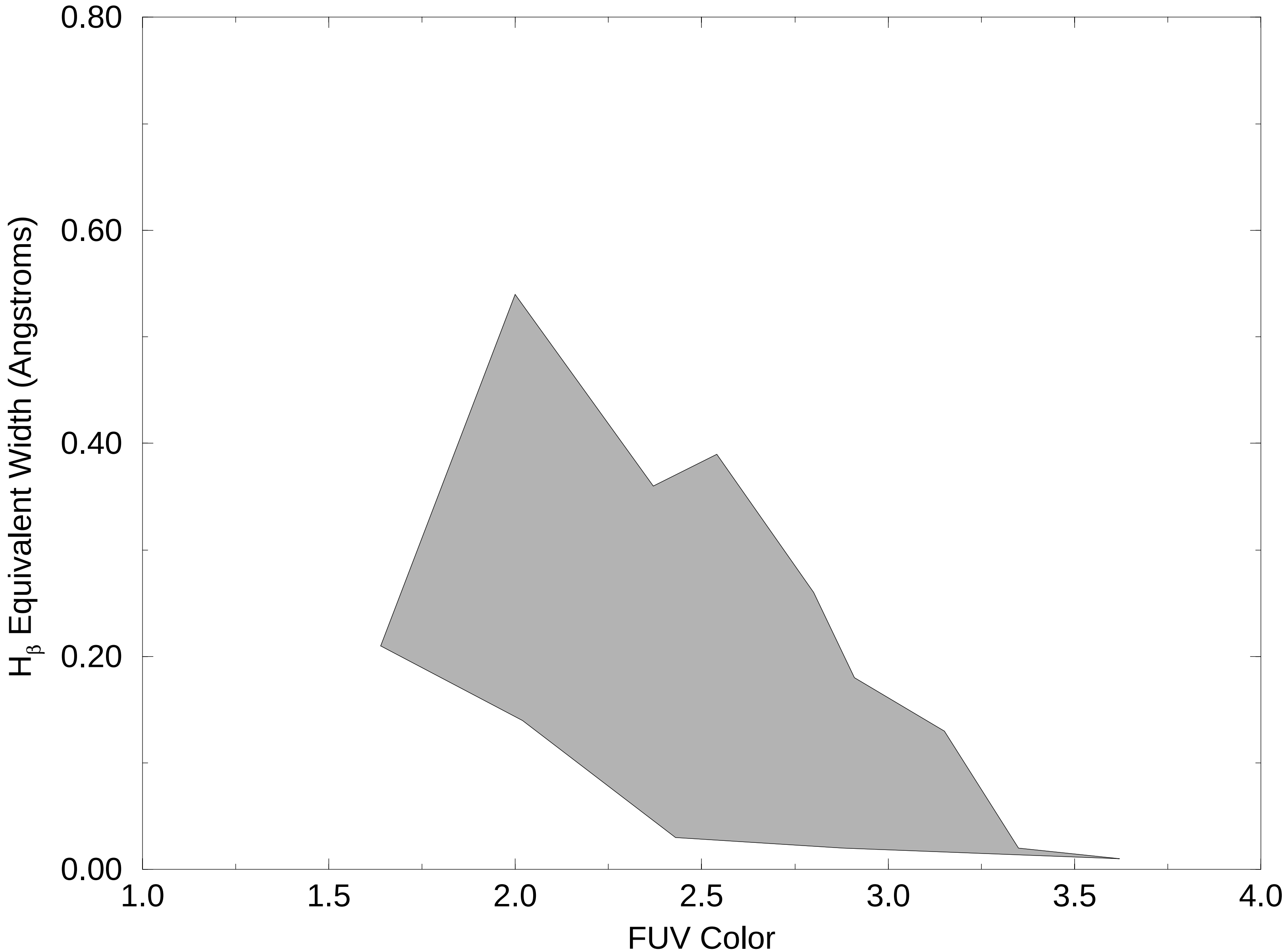
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0.60
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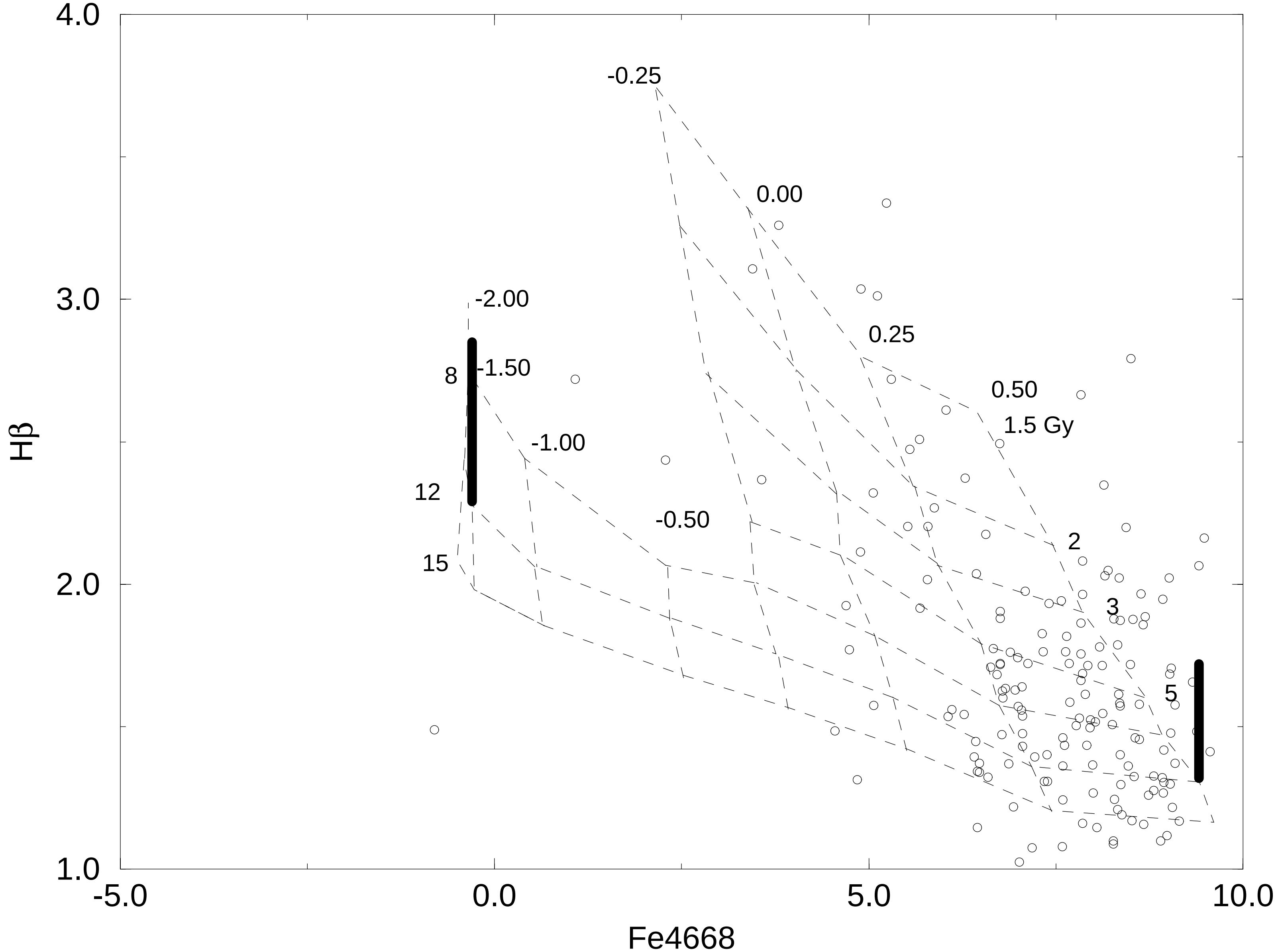
FUV Color



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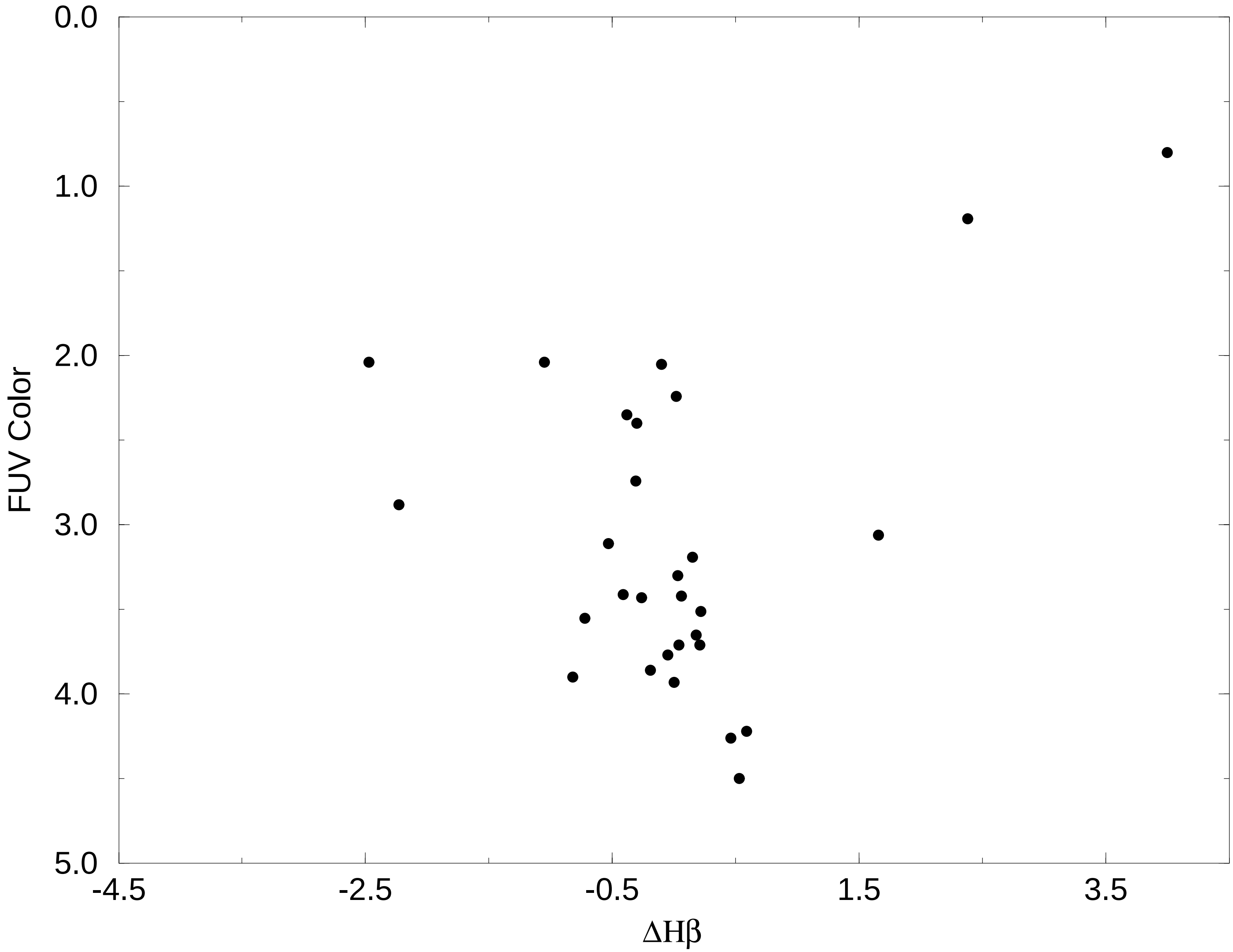

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